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Physics
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Relation to Medicine

A REPORT
by the
EDUCATIONAL COMMITTEE
of the

American Physical Society

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To the Members of the American Physical Society:

The following report was prepared by Professor W. J. A. Bliss and Dr. P. E. Klopsteg, members of the Educational Committee, with the co-operation of Dr. H. B. Williams, Professor of Physiology in Columbia University. We are greatly indebted to Professor Williams for his very valuable help in this work.

This is the second of a series of reports planned by the Educational Committee. Each of the series will be published as soon as it is ready and the available funds will permit.

To meet the expenses of publishing their reports, the Educational Committee is dependent on voluntary contributions from members of the Physical Society. We, therefore, bespeak the generous support of all who are interested in the work of the committee.

Respectfully submitted,
A. Wilmer Duff, Chairman,
W. J. A. Bliss,
H. W. Farwell,
Paul E. Klopsteg,
E. P. Lewis,
H. M. Randall,
L. P. Sieg,
D. L. Webster.

Correspondence with reference to the subject of this report should be directed to Professor W. J. A. Bliss, Department of Physics, Johns Hopkins University, Baltimore, Md.

To the Educational Committee of the American Physical Society:

Gentlemen: Your sub-committee on the relation of physics to medicine was organized in March, 1921. In view of the many questionnaires that had recently been circulated and particularly that of the sub-committee on physics and engineering, which was about to be sent out and which covered very fully the details of elementary college teaching, it seemed advisable to proceed differently. We, therefore, invited the cooperation of the teachers of physics in several institutions selected as representing different types and localities, the teachers being men who were known to us as experienced in teaching premedical students. These were: Professor Farwell, Columbia; Professor Richtmyer, Cornell; Professor Lemon, Chicago; Professor Lewis, California; and Professor Blake, Ohio State, to which may be added the experience of one of this committee at Johns Hopkins. To these, inquiries were addressed, explaining the objects of the committee, and asking them to inform us fully as to their own methods and the changes which they thought should be made in them. A list of questions was sent, which was intended to suggest the lines along which information was sought rather than to limit the replies to individual questions. The committee begs to acknowledge its very great indebtedness to these gentlemen, and to other members of their departments, for the very gratifying cooperation which they have given and for the interest and labor shown in their full replies.

Meanwhile the members of the committee extended their own information, by seizing every opportunity for conversation on the subject with other physicists, and by correspondence and personal interviews with medical men. To this they added the results of the very valuable correspondence carried on by Professor Wendell, during the survey of the general field of education in physics, which led to the selection of the question assigned your committee as one of the important ones pressing for consideration.

In view of the method adopted by the committee we submit the following as a preliminary report intended as a basis for discussion, and to secure this we advise that it be given as wide publicity as possible among physicists and medical authorities, and that replies and criticisms be invited.

Respectfully submitted,
William J. A. Bliss, Chairman,
H. B. Williams,
Paul E. Klopsteg,
Sub-committee.

PHYSICS IN RELATION TO MEDICINE

I. Importance of Physics to the Progress of Medicine

In the middle of the last century, largely through the influence of Liebig, a great impulse was given to the application of chemistry to medicine and physiology, and for a long time physics was by comparison neglected. Such phenomena as diffusion and capillarity were recognized as important, as were obvious applications of a few other parts of physics, for example, to sight and hearing, and this led to the requirement of some small preparation in physics for the study of medicine. This was gradually increased with the growth of laboratory equipment in medicine, applying all branches of physical measurement. The present position of physics, however, is not simply the result of the natural spread of similar applications. It is much more revolutionary. The rising importance of physical chemistry; the application of thermodynamics to chemistry; the extraordinary development of physics in the last quarter century, of which the discoveries arising from X-rays and radioactive transformations are only a part; all these have placed physics in a fundamental position as regards science in general. Thus physics has become doubly important to medicine; first through the growth of its applications, of which some examples are enumerated below; secondly, and fundamentally, because it is essential to an understanding of other sciences, the medical importance of which has been longer recognized.

Naturally a strong demand has developed, not only for increased preparation in mathematics and physics for the student entering the medical school, but for increased participation of physicists in medical research. While the advance of medicine in the last century may be chiefly attributed to chemistry, biology, bacteriology, and kindred sciences, the key to the future seems to be sought more and more in physical chemistry and physics. A few of the applications of physics to medicine may be cited as illustrations.

General Physics. Inertia, moment of inertia, and elasticity are of importance to the physiologist in relation to properties of instruments used in various types of measurement, such as the measurements of hemodynamics. In order to make accurate measurements or to know the accuracy of a measurement which is being attempted, connecting mechanical movement with time, knowledge of the natural period and damping forces of the apparatus used is needed. The biologist must often design his own instruments and develop his own methods; in order to do this successfully, he requires enough theoretical knowledge to predetermine the properties which a particular design and choice of materials will give. There are plenty of examples in biological literature of the enormous waste of time and effort which lack of such knowledge has caused.

Construction, care, and reading of barometers and correction of barometric readings to standard conditions are methods constantly applied in biological work. Diffusion of gases, partial pressures, solution of gases in various solvents, and the relation of these phenomena to pressure and temperature changes are of enormous theoretical importance in biology and should be well understood.

The phenomena of osmosis, adsorption, etc., are of the utmost importance in the formulation of biological theories. Such subjects as digestion, secretion, excretion, and the like cannot be discussed without some knowledge of them.

Sound. The fact that we have a special sense organ for the perception of sound, an organ whose integrity is a matter of great practical interest, is of itself an indication of the importance of a knowledge of the physical nature of sound.

The investigation of the normal function of the ear and of its pathology requires first of all thorough knowledge of the underlying physics. One might mention such investigations as the relation of phase differences at the two ears to ability to locate the direction of sounds, and the studies of the relation between frequency of the sound and the minimum amount of energy required to produce the sensation of hearing, as examples of physiological studies requiring knowledge of physical acoustics. Moreover, the physician constantly employs his ears in the diagnosis of diseases of the heart and lungs, and particularly in connection with the use of aids to hearing and devices for intensifying and recording these sounds he needs precise knowledge of acoustics.

Heat. The body of a warm-blooded animal performs the functions of a thermostat, provided with various chemical and physical means for regulation. The various reactions which go on within it seem to require this nice regulation for the efficient operation of the mechanism.

The energy exchanges between the living body and the food which constitutes its fuel have been made the subject of careful investigations, which are still going on. Precise studies of such changes in man were made with Professor Atwater's respiration calorimeter, the successful development of which, for the heat measurements, was largely due to the cooperation of a physicist, Professor E. B. Rosa. It is particularly desirable to secure similar knowledge of such energy changes in disease, and calorimeters on like principles have now been applied to such problems also; for example, diabetes, in which the normal ability to utilize carbohydrates as fuel is impaired; typhoid fever, in which the maintenance of the body at an elevated temperature over prolonged periods requires the expenditure of greatly increased amounts of energy; and various other conditions. The entire problem of sustained animal life depends upon that of nutrition, which, in turn, involves heat energy studies. If we ever come to a clearer understanding of the problems of secretion, assimilation, production of muscular energy, and others of a fundamental nature, it seems likely that no small part in the advance will be played by a study of the energy relations. From theoretical aspects a knowledge of thermodynamics seems highly desirable for the biologist.

Of less fundamental character, but no less important, are such matters as thermometry, including mercury-in-glass, electrical resistance, and thermo-couple thermometry, knowledge of stem corrections, etc. These are necessarily involved, in some form, in all calorimetric work, in investigations of fever, etc. Knowledge of the laws of conduction and radiation of heat is desirable in connection with apparatus used by biologists, as well as in consideration of the living organism itself.

Light. The effect of light in modifying the course of chemical reactions is almost too well known to need comment. The relation between the growth of green plants and sunlight has long been known. A more recent development is knowledge of a direct relation between exposure to light of certain wave-lengths and the prevention of rickets, a disease of childhood. One of our most important sense organs is the eye. A knowledge of geometrical optics and of various optical instruments is absolutely indispensable to the ophthalmologist. Optical instruments of many kinds are in use by biologists. Photography plays a part of increasing importance in scientific investigation. The spectroscope has long been used in chemical investigations. The microscope is preeminently the biologist's own instrument. The spectrophotometer promises to become a powerful instrument of research in biological chemistry.

The problems of physiological optics have been but little cultivated by physiologists since the time of Helmholtz, and many of these should be made subjects of research, notably color vision, vision itself, the part played by the ocular pigment and the visual purple, etc. In recent years physicists concerned with optics have been forced to make studies of some of these physiological problems bearing on the use of the eye in physical measurements, for example, studies of visual luminosity curves in connection with photometry of light of different wave-lengths. The physiologist who undertakes such problems as those mentioned above must of necessity be well informed on these investigations and on physical optics in general. There is great need of a course in ophthalmology of such a comprehensive character as shall really fit the graduate for all the various exigencies of practice. It should naturally include the pathological and surgical aspects of the subject, and also thorough and adequate instruction in geometrical optics and physiological optics. There are few men at the present time competent to give really adequate instruction in the last, and, so far as the committee are aware, no medical school offers to a graduate in medicine a comprehensive course comparable with that outlined above.

Electricity and Magnetism. There is perhaps less reason to direct attention to the need for knowledge of these subjects in connection with biology and medicine. Few persons in any walk of life today can carry on their work without some elementary knowledge of electrical phenomena. Electrical instruments in great variety and for many purposes find application in the study and practice of medicine. The use of X-rays for making shadow pictures of inaccessible parts of the human body is familiar to all, and these rays together with the radiations from radium and other radioactive substances are used in the treatment of certain diseases. This brings with it the need of precise measurements, and in some biological laboratories at the present time will be found such devices as ionization chambers with their accessories and even X-ray spectrometers.

The increasing tendency to apply the methods and viewpoint of the physical chemist to biological problems has made the determination of hydrogen ion concentration by electrical methods a matter of daily routine in many biological laboratories. The electrolytic conductivity of the body fluids is another subject applying physical chemistry and physics. The electrical action current of muscles has been a well known physiological phenomenon for years. Until recently it was considered as of academic and theoretical interest only. Within a decade the measurement of the action current of the heart has come to be a routine method of diagnosis in many hospitals and clinics. This has been made possible through the development for this specific purpose of a special instrument, the string-galvanometer. It is significant that this instrument was developed not by a physicist or engineer, but by a physiologist and physician, Professor Einthoven of Leyden. The history of this development indicates very well the advantage of an adequate knowledge of physics and mathematics on the part of the biologist.

More recently the development of the three-electrode vacuum tube has provided a powerful tool of research. The possibilities of this instrument were promptly recognized by several biologists, and it is likely it will be extensively employed in biological investigations. One might mention recent researches by Forbes and by Bovie and Chaffee at Harvard, as illustrating applications of vacuum tube amplifiers to biological problems.

It seems highly probable that the photoelectric cell will find a useful place in biological research before long. Quite apart from the use of photoelectric apparatus in research, the phenomena of photoelectricity have an important bearing on optical-chemical-biological theory.

This outline is intended to be suggestive. Any attempt to catalog the manifold inter-relations between physics and medicine in a thorough and complete fashion would attain the proportions of a volume. The ideal to keep in mind, in preparing a student to apply physics to the problems of medicine and biology, is not that he be given special facility in this or that branch of physics, which may seem to bear a definite relation to a particular phase of his subsequent work. The aim should rather be to teach the *subject* in sufficient generality and with sufficient thoroughness to enable the student at any time to extend his knowledge along any special branch of physics as the circumstances of his later work may require. No one can tell what the medicine of even 1930 may be like. Science grows and changes and the prospective scientist must be so trained that he may be able to grow and change. Who could have foreseen in 1880 the lines along which physics would be advancing in 1920? Who knows but that the medical student of 1940 may be guided in his theories of life phenomena by a theory of atomic structure so far perfected as to be of great service in the contemplation of the complex problems of biology?

It is hardly to be expected that students preparing for medical study or even for a career of investigation in biological fields will, at the present time, undertake anything like the preparation in physics which would be regarded as suitable for a prospective investigator in physics. In chemistry, the preparation of the present-day biologist is often as good as that of any professional chemist. This is as it should be, for the enormous importance of chemistry in biological investigations has been demonstrated. That physics may be able to furnish the biologist (and the chemist also for that matter) with most powerful methods of research, theoretical as well as experimental, is beginning to be recognized. The demand for increased training in physics will eventually come from the students themselves. When it does, the amount need be limited only by their ability to assimilate and use it. It is necessary that teachers of physics should be aware of the many points of contact between their subject and that of the biologist, and that workers in both fields should see to it that students are made aware that physics for the biologist is no academic luxury, that it is a necessity, of which, perforce, he will be unable to secure enough, and of which he should secure so much as will enable him to obtain a foothold and advance by his own efforts, when time and opportunity shall have indicated to him along what line of physical theory or technique he will find most assistance in the biological problems he undertakes to solve.

II. PHYSICISTS FOR MEDICAL INSTITUTIONS

While more adequate training in physics for medical men in general seems essential, it must be recognized that mastery of that science cannot be expected of them, and that at present even a sound working knowledge is rather unusual. There is, therefore, urgent need for advice from trained physicists, constantly available in medical institutions, and for the cooperation of physicists as such in medical research. It is, therefore, desirable that there should be one or more physicists as part of the regular staff of such an institution. If it is connected with a university, these men might be members of the department of physics. Or, if more convenient, they might form a separate group, as is usually the case with physiological chemists, for example. But, in that case, special care should be taken that they preserve the closest relation with the department of physics, both for the coordination of instruction and research by the two groups, and in order that the men engaged specially upon medical applications of physics may keep fully up with the science as a whole. It is obviously necessary that they should remain good, progressive physicists, just as it is desirable that they should have had initially a broad, sound training in pure physics, rather than one that has specialized too early in existing biophysical methods.

To be qualified for the work here referred to, a physicist should possess experimental ability of a high order and ingenuity in the application of a wide range of physical methods; but, while these qualities are essential, the great problems need men who can combine them with the ability to apply physical theory to the phenomena of medicine. Such a physicist should also be cooperative and interested in the problems of others, rather than inclined to shut himself up in his own personal investigations, and, as a detail of organization, it is important that he should not be so closely identified with some one department that he will be regarded as its particular property. He should by all means be provided with a laboratory equipped both for research and for instruction in the use of physical methods appropriate to the work of the institution, but he should be ready to leave it when wanted to give help and advice. In other words, the situation calls for men who can not only carry on independent research, but who can also supplement the lack of knowledge of physics of their colleagues. In view of the ignorance of the physicist as to the problems of biology and medicine, most men called to such positions would have to begin with such collaboration.

III. STUDY OF PHYSICS IN PREPARATION FOR MEDICINE

The attempt to provide better instruction in physics for medical students, whether in school, college, or the medical course, leads to a dilemma, between what appears to be the urgent need of more adequate preparation and serious objection to any further lengthening of the medical and pre-medical course. A distinguished professor of clinical medicine says that a student in his classes should have a preparation in physics and mathematics equal to that which must precede a graduate course in physics. An equally noted professor of physiology thinks that it would be easier to teach an electrical engineer the medicine necessary for a study of physiology than to teach the present medical graduate the necessary physics. Opposed to these are the statements of wise and experienced authorities on medical education who urge that the requirements for a degree in medicine are already too high: that they deter men from entering the profession. It has been stated that the number of medical graduates is less than the loss by death and retirement, but accurate statistics gathered by the Council on Medical Education of the American Medical Association prove that this is not the case. The lack of physicians in country districts appears to be a question of distribution rather than total numbers; and the remedy is to be sought in improvement in the conditions of country practice rather than in the medical curriculum.

Assuming that it would not be advisable to increase the total requirements beyond the present standards of the best medical schools, more time for physics must be sought by lessening that allotted to some other study, but here also the outlook is not encouraging. The doctor, like the lawyer or the clergyman, should be a man of liberal education, to broaden his understanding and sympathy with his patients and to command their confidence. His profession is rooted in the classics by history and terminology and he needs modern languages to keep up with its progress. Institutions which require two years of biology might perhaps reduce this amount, in view of the fact that the medical school can meet a deficiency in this better than one in physics. It is also possible that there is unnecessary repetition of similar details in the first course in chemistry and that this work might be condensed with advantage. The relief from these changes would, however, be small, and though they were suggested by medical educators of high standing and experience, they were opposed by others who felt that the doctor is resorting too much to the laboratory, and getting out of personal contact with his patients. They feared that greater emphasis on physics in the curriculum would lead to an over-estimate of the value of physical instruments in medical practice. Such a tendency might be avoided if the emphasis in the course in physics for medical students is placed on the teaching of pure physics as a basis for the medical sciences, rather than on any narrow technical application.

The best way to meet the difficulty is to provide two grades of preparation in physics for the study of medicine. The vast majority must, at least for the present, be limited to the "one year of college physics" now generally required. A few, marked by special ability in mathematics and physics, but desiring to apply these to medicine, may add a second course, which might be accepted by the medical school in lieu of some of the required biology. It is not intended here to suggest that students preparing for medicine should choose during their college course whether they will enter practice or devote themselves to research, but merely that each should follow his natural inclination as between a second year of biology and more physics, and that the medical school should admit the alternative, in the belief that a limited number of men so prepared will be of value in the medical field, and that the majority will choose the biology. The committee, therefore, strongly recommends that an elective course suitable for such men should be provided, and should normally be taken in the third or fourth year of a four-year college course. It would be difficult to provide for this option in a two-year or three-year college course, but if the medical school could condense some of its work in anatomy and kindred subjects, it might be possible to introduce it as an elective in the medical school. In addition to the required course and elective already mentioned, there should be provided, in the medical school, instruction in physics as directly applied to medicine, as part of the duties of the physicist recommended in another section of this report. Two such courses, Biophysics 1 and 2, were given with gratifying success at the Johns Hopkins Medical School in the first semester of 1921-22.

IV. COURSE IN GENERAL PHYSICS

Preparation in physics for medicine being usually limited to one course, the committee has necessarily made it a subject of careful investigation.

1. *Purpose.* The extended field of physics and of its application to medicine renders it impossible in a single course of reasonable proportions to convey even an elementary grasp of the principles, familiarity with all the most important physical phenomena, and practice in the technique of their application to medical instruments. At which should one aim? Shall one try by many lectures, illustrated by experiment and by lantern slides, to leave the student with a picture of the multitude of beautiful and interesting phenomena, and particularly those obviously applicable to medicine, and to store his mind with rules and formulæ for applying them? Shall we teach him to take X-ray photographs, to use a refractometer and a polarimeter efficiently, and the technique of the sphygmomanometer and the hydrogen electrode? The student himself will think our course practical and interesting and apply himself to it more if we do all these things, and for that reason the illustrated lectures at least have their place. But, as already stated earlier in this report, the essential purpose of the course is to give a *grasp of principles,* the structure of the science as a connected whole, and particularly those concepts and laws which underlie all the physical sciences. The importance of this or that physical phenomenon or instrument will wax and wane; will depend on the future career of the student, and change with the development of medicine. But he who really grasps and can use such concepts as acceleration, force, mass, momentum, temperature, pressure, electric charge, current; who has a clear idea of energy and its conservation and can apply it correctly to work and heat changes, to electrical potential, and to the phenomena of the electric circuit; to whom the kinetic theory of matter is real and vivid; and who understands such special topics as elasticity, periodic motion, and waves: that man has the essential foundation for a structure that will grow as he grows. Fortunately most of those of whom we sought advice agree to this. The committee was particularly impressed by the fact that medical school authorities were more emphatic than were the physicists we consulted in recommending for medical students a *good, stiff, systematic,* and general course, similar to that recommended in Report Num-

ber 1 for students of engineering, and not one emasculated for a supposedly unmathematical brain. For example, our replies from physicists lay much less stress than do those relating to students of engineering upon adequate mathematical preparation and on numerical problems. The medical authorities do not seem to desire this distinction carried as far as it seems to be. Teachers of medicine regard physics as the main opportunity for training in that clear and precise thinking which is necessary before a scientific problem can be stated in numbers. They seem to value this aspect of the study as a corrective for that very aversion to mathematics which the physics teacher notices and which inclines him to more qualitative methods. The committee may, therefore, once more repeat that the main purpose of this course is a systematic and fairly rigorous development of the fundamental principles and concepts of the science as a whole, together with abundant reference to phenomena and applications, but as illustrations rather than for their own sake. *The student must be left in a position to extend his knowledge with reasonable confidence and success by his own efforts as his future interests develop.*

2. *Time Required.* Great diversity was shown in the replies as to the actual time devoted to the study, and its distribution. Nevertheless the committee is able to fix with confidence the minimum total time required for the accomplishment of the purposes outlined above. This has been done by comparing the time now devoted to the typical courses studied and the suggestions and criticisms of the instructors, with time allowed engineering students for a like course. Admitting that the latter apply physics more constantly in their profession, the engineering studies themselves afford a constant review and amplification of the fundamental knowledge derived in the physics course. It would also be easier to name fields of physics that the engineer does not "need in his business" than to make similar exclusions for medicine. Noting what has actually been accomplished in the first course in physics by engineering students, the general complaint of inadequate time for that course, and the fact that those students are undoubtedly more apt in physics than the premedical ones, we cannot consider courses which allow the latter only half the time allotted to the former as satisfactory.

We, therefore, suggest, as the minimum, eight or nine per cent of an average four-year college education. That is, if given in one academic year of some 30 weeks, the study should count about one-third of the work for that period, or approximately 12 semester hours. In other words, we estimate that the average premedical student will take at least 500 hours, including home study and reading as well as instruction, to attain such a grounding in the science as is absolutely necessary, if he is to apply and extend his knowledge by himself. If less is given, the course will either be robbed of interest by scanting the presentation of phenomena and applications, or the unity of the science will suffer and it will fall into disconnected topics; or the definiteness of the instruction will suffer by curtailment of laboratory work or of numerical problems.

3. *Distribution of Time by Subjects.* We can recommend as good practice that about one-third of the total time be devoted to mechanics and properties of matter; one-third to electricity; one-third to heat, wave-motion, sound, and light. There is

a tendency, which is apparently correct, to devote rather more time to the third subdivision than to either of the other two, but this should not be carried too far. In all parts of the subject some attention should be devoted to recent advances in physics.

4. *Distribution of Time among Classwork, Laboratory Work, and Home Study.* The total time has purposely been stated as generally as possible in order to give the instructor a fair opportunity, but allow the greatest freedom in the manner in which it is used. A subdivision in accord with existing practice in most institutions would be three to four hours per week of lecture and recitation, one three-hour period for laboratory work, and a second like period to be used either for more laboratory work, problems, or conferences, as the progress of the course suggests. This would leave six or seven hours per week for study and reading, which is none too much. For the superior student it would be highly desirable to increase the time devoted to reading and study, and lessen that for class instruction. A single illustrative lecture and one laboratory period a week with an hour of private conference with an instructor would, perhaps, be the irreducible minimum even for the best students. It is understood that such men should devote at least ten or twelve hours a week to reading.

A contrast to the schedule suggested is afforded by the course at the University of Chicago—one lecture and four two-hour laboratory periods weekly for 33 weeks. The actual teaching takes place almost entirely in the laboratory periods, which are really conferences between instructor and students in small groups, and combine all the elements of recitation and problem work as well as experimentation. Well carried out, as it appears to be, the plan is admirable. It affords freedom and flexibility to adapt the teaching to the individual and the most favorable opportunity to make clear what is not understood. The difficulty would seem to lie in securing adequate instructors and sufficient space.

5. *Formulation of the Requirement.* In default of a better method the medical schools must probably continue to state their requirement in hours devoted to the subject in college, and specify their distribution between class and laboratory. The requirement should not be administered in a book-keeping spirit, but should be regarded merely as a rough measure of the extent of training desired and the relative weight attached to theory and experiment. It would be better, in estimating the merit of individual courses, to compare the time included and the text-book used. A rapid inspection of the laboratory note-book will serve as a guide to the quality of the applicant and the standard of the instructor. An entirely unfamiliar course might be referred to the department of physics. In any case the course should be accepted or rejected as a whole unless there is a clear inadequacy in some principal subdivision; for example, no light or sound, or no electricity. The committee sought for suggestions for stating the requirements otherwise than by hours of instruction. Only one was received—an examination set by a committee of physicists and medical men.

6. *Separate Instruction for Premedical Students.* In many institutions students in General Physics are divided into engineering and academic groups, to which entirely different courses are given, and sometimes again according as they have or

have not had physics in school. A further subdivision by which premedical students might be given a special course is not regarded as feasible. The committee accepts this as sound policy, particularly in view of the movement to secure special consideration and more rapid progress for the superior student. One of our correspondents was very eager for a separate course for premedical students, but the general opinion was that little differentiation would be possible in any event, except as to illustrative material or in choice of laboratory experiments. The time available does not get us to the parting of the ways. A section of the ablest students from all categories would seem much more desirable for its broadening effects, more rapid progress, and the substitution in part of reading for text-book study and formal instruction, and this would allow much greater freedom in the adaptation of the work to the interest of each student.

On the other hand, it is highly important that teachers of physics who have many premedical students should familarize themselves with the applications of physics to medicine and biophysics, draw on the material extensively for illustrations, and provide copious references for those willing to read. This will help to open the eyes of the student interested in medicine to the importance of physics to him and thus enlist his interest, whether or not his predilection for medical topics is as developed at that stage as some educators believe.

7. *Prerequisites and Arrangement of Courses.* The fundamental purpose of the course, as has been stated, is to prepare the student to apply the science and to extend his knowledge by himself. It is difficult to do this if his training in mathematics has not been adequate. The course here recommended would come in the second year of college work, and should be preceded by a year of college mathematics, planned so as to meet the needs of the science student. In the course in mathematics, as well as in that in physics, students should be taught to regard equations as statements about physical things, rather than as mere relations between numbers. An increase in the amount of mathematics would not, in itself, meet this requirement. The emphasis needs to be laid on the nature and quality of the work.

This sequence of courses might be difficult in a two-year pre-medical course. Some sacrifice of standards in every respect then becomes necessary. It is highly desirable that students who are to take physics in the first year should enter with some knowledge of trigonometry, logarithms, and the elements of co-ordinate geometry. If a student has neither studied trigonometry in school nor been able to acquire, by outside study, the very elementary knowledge of it that is needed in the study of physics, the teacher of that subject is compelled to resort to one of several disadvantageous expedients. He may stop to explain the elementary trigonometrical terms as he needs them, or arrange with the mathematics teacher to do so as early as possible, and take up light, which requires the least mathematics, first, instead of following the usual order. In any case he sacrifices time and efficiency in the presentation of his own subject.

8. *Lectures, Recitations, Conferences.* The committee refers to Report Number 1 on Engineering Physics, for a detailed discussion of teaching methods in the General Course. We may mention briefly a few important points and note some differences in our replies and those to the engineering questionnaire.

The committee calls attention to that part of Report Number 1 which emphasizes the importance of good experimental lectures as a means of interesting the students. Without such the course becomes dry and abstract. As a means of instruction, however, our replies attach, perhaps, less importance to them than to work in sections, placing their chief reliance on work in the latter. For a section 25 students is an undesirable maximum, 15 or 20 being preferable. In this respect and also as regards the general conduct of the recitation, we are in agreement with teachers in engineering colleges (Report 1, p. 19). But even larger recitation sections are a smaller evil than requiring the same instructor to teach several sections. Thirteen to fifteen hours of instruction, with the attendant correction of exercises and handling of apparatus, should be the limit for each teacher. Lessons on assigned topics are not thought advisable, but frequent short written tests should be given, and the remainder of the time should be devoted to conferences, that is, to discussion intended to bring out difficulties, to the suggestion of points of view not in the text, and to working problems.

An occasional lecture at the usual hours ought to be given by some one other than the regular instructors. For example, at Chicago, Professor Michelson talks on elasticity and interference, A. P. Matthews, a physiologist, on capillarity as applied to biology, and at Johns Hopkins, Professor Wood on the liquefaction of gases. This stimulates the class and gives them a glimpse of a level that cannot be maintained in the regular routine. It differs from the sporadic lecture, open to the student body, by being specially to the class and by the possibility of better coordination with its progress.

9. *Laboratory Work.* No part of instruction in physics has been more criticized than the laboratory work. It is said to lack the spirit of experimentation, to be nothing but a training in technique, to be hopelessly uninspiring and dull, and to fail to take advantage of the natural interest of the student in physical phenomena and apparatus. The fact is that our laboratory work is the offspring of "Physical Measurements" and it is possible that it takes too much after its dam. This committee finds that laboratory teachers would like to do the things they are criticized for not doing, but that there are usually difficulties in the way of any radical change in the type of laboratory instruction, and also that the first course in physical laboratory work is looked to for a certain very definite training in methods and instruments. The problem of the laboratory course, as of the rest of elementary instruction in physics, is to do the best with a certain limited amount of time and money. The laboratory teacher tries to use these to increase the student's knowledge of physical laws and phenomena and to help him to a more definite and concrete idea of them, and, secondly, to fulfill in some measure the expectations of other departments as to training in technique. On the whole our correspondents feel that they are meeting with a certain measure of success in reaching these limited objectives, and that the development of the research attitude must be postponed to later and smaller courses. Professor Richtmyer describes a very interesting second laboratory course in which the student is assigned some definite substance and given the problem of determining a great many of its physical properties, density, refractivity, conductivity, and so on, selecting his own methods. Given to only a few students, it is highly

successful, but he points out the hopelessness of applying such methods to classes of several hundred.

On the whole the happiest suggestion for such classes is due to Professor Farwell. Outline a definite piece of work to be done with definite equipment, but make the directions brief, so as to leave details to the student's ingenuity. If the man finishes before the end of the period, encourage him to try further experiments of his own, without requiring him to submit notes. It must be understood that in any case every student remains in the laboratory for the entire period and makes the best use he can of his time. The system of marking should be such as to encourage quality, intelligence, and comprehension of the problem, rather than quantity.

The interest of the student depends mainly on the selection of the experiments and on the right sort of standard as regards numerical results and accuracy. He generally likes to use a good instrument, which gives data that appeal to him as reliable, and he likes to get a good result. He is discouraged by the reverse and his fickle interest is lost. The moral is to furnish good equipment, though care must be taken that it is not the elaborate kind that conceals the principle and eliminates skill. The best labor-saving instruments of research laboratories would often be the worst for teaching. The student does not like work of which the obvious purpose is to learn how to use some instrument, and technique must be largely a by-product, acquired unconsciously with a more interesting goal in view. This requires all the more watchfulness on the part of the instructor to prevent incorrect and careless habits. In short, while the instructor ought to distinguish between intelligent work and a good result, he ought not let his students get the idea that the result makes no difference.

What has been said applies to quantitative experiments, which the replies of the committee indicate to be the most common type, and very properly so, since the object is to do illustrative experiments on laws and relations of physics which are mainly quantitative. Some purely qualitative experiments are given, and also others in which the observations are numerical but cover a variety of rapid tests rather than a single more accurate determination, for example, in comparing the same physical property, such as specific heat or resistivity, in several substances. The committee would like to see this type of experiment more frequent, and also the custom of bringing apparatus commonly shown in lectures into the laboratory and letting the students handle it.

The committee was glad to find that most of its correspondents felt that the main duty of the instructor in the laboratory is to draw out the student's knowledge of physics and of the work in hand, and to judge his merits on the spot and not on the basis of a written report. He is not there simply to help the student adjust apparatus and get data. It is evident, however, that we tend to slip into the second attitude, and to keep us teaching physics and to secure the proper emphasis on the student's work in the laboratory require effort and safeguards, one of which might be the abolishment of the report written at home. Most of the engineering replies and some of ours, however, regard the written report as valuable for the sake of the student, though the issue is not clearly met whether the report is worth more than an equal amount of time spent in preparation for the experiment beforehand, or in reading.

But we know when we get the report, and perhaps if we abandon it we may not be sure whether we get the equivalent.

Our replies and the engineering ones agree that 12 or 15 students to an instructor in the laboratory, or one instructor and an assistant to 25 is good practice. Sections of 20 to 25 students per instructor are common, but are considered too large.

With the small section a laboratory examination is needless, for the larger ones it is desirable, a practical test being preferable. At Johns Hopkins a practical test at the end of the year used to be required of all students with laboratory grades below 85. Each student spent 45 minutes with each of four examiners, who set some simple task, saw how he went to work, and asked a few questions. Even with eight or ten students in the room at a time, it was easy to gauge their qualifications, and the test was highly successful and valuable. But it was found so laborious that, with increasing classes, a three-hour written examination has been substituted, distinct from the class examination. This seems to be decidedly worth while.

10. *Problems.* This part of the work is looked upon as of the highest importance in the engineering replies, and in most of ours, though some report that they have no time for it. It is agreed that not much reliance can be placed on problems done at home and handed in. The approved method is to require this as part of the student's preparation, but to base grades on work done in class only. The instructor should work problems himself to show how they are done and call on members of the class to do others, and all should be discussed by the section. This is conceded to be the best way to teach, but it is terribly time-consuming, and the fact that it is regarded as necessary points again to lack of responsibility and purpose on the part of the college student as a source of inefficiency.

V. ELECTIVE COURSE IN PHYSICS FOR PREMEDICAL STUDENTS

In Part III of this report the committee has recommended that, in addition to the course in General Physics required of all premedical students, there should be a suitable elective course, to be taken only by such as have time for it, and ordinarily in the third or fourth year of college. This has not been so fully studied as the general course, and its exact character and content must depend largely on the resources and personnel of the institution offering it. It should consist largely of laboratory work, which it would be comparatively easy to adapt to the special needs of students going into medicine. Whether it would be possible to give a lecture course specially for them would depend on the resources of the department and the demand. It ought to be possible to plan a reading course, at least, or a course of lectures suitable for advanced men in biology and chemistry as well as those specially interested in medicine, for example, on radiology, including heat, light, X-rays, and radioactivity: or, as suggested by Professor Richtmyer, "Radiation and Life." It ought to be a thorough treatment of a limited field rather than an attempt to cover general physics over again.

In the laboratory the aim should be to teach the correct use of physical instruments and methods specially applicable to medical problems. More stress should be laid on precision than in the first course and the apparatus should be of a standard type used in research rather than the simple form advised for elementary students. It may be assumed that the student also studies physical chemistry and the work should not duplicate measurements likely to be taught in that course, such as boiling and melting points, work with an analytical balance, conductivity and hydrogen electrode determinations. Perhaps it would be desirable that chemists and physical chemists should be more familiar with the physical principles and sources of error in their measurements, but the remedy is clearly in closer relations between the departments, rather than in duplication of the work. Omitting these one might suggest some of the following:

EXPERIMENTS SUGGESTED FOR ADVANCED ELECTIVE COURSE

Mechanics.

1. Density and specific gravity.
2. Manometers; sphygmomanometer and sphygmograph and their calibration.
3. Viscosity; viscosity determinations based on flow through tubes, and by rotating cylinder or disk.
4. Surface tension.
5. Measurement of long and short time-intervals.
6. Production and measurement of low pressures.

Heat.

7. Thermometers, including study of lag and stem correction.
8. Resistance and thermocouple thermometry.
9. Study of heat conduction and loss, and insulation.
10. Regulation of constant temperature baths and ovens.
11. Principles of calorimetry.

Light.

12. Refraction; spectrometer and refractometer.
13. Microscope and reading telescope.
14. Spectroscope, spectrograph, and spectrophotometer.
15. Colorimetry.
16. Photometry.
17. Polarimetry.
18. Radiation and measurement of wave-length and of radiant energy.

Sound.

19. Production and measurement of tone, pitch and intensity.

Electricity.

20. Measurement of resistance by d. c. and a. c. methods.
21. Measurement of current, direct and alternating.
22. Measurement of voltage, direct and alternating.
23. Galvanometers and their applications.
24. Cardiography with the string galvanometer.
25. Vacuum tubes and their use as amplifiers and as oscillators.
26. Instruments used in radioactivity measurements.
27. X-ray technique.

In order to make his teaching more effective, the instructor in this course should keep in mind that for this particular group of students physics is only the means to an end. He should, therefore, endeavor to make the course as practical and concrete as possible without sacrificing the teaching of fundamentals. He should consult freely with those members of the medical faculty who are doing experimental research in order to obtain an insight into the physics of their problems.

Training in the Judicious Use of Instruments and Data. More than ever before is the modern medical man dependent upon laboratory instruments and data. Should he by chance enter the research field, his real success is likely to be almost entirely due to his knowledge of his apparatus and as to what his results are quantitatively worth. The Committee believes that an adequate training in physics will include a sufficient emphasis upon the theory of measurements. While most laboratory courses give some attention to measures of accuracy, it is frequently perfunctory only, and often considered only in connection with so-called "precision" experiments. As a matter of fact, it is extremely important that the man who is able to secure only an inaccurate result, should know enough not to attach undue importance to it. The field of medicine, by its very nature, affords many corners where even the best observers can see but dimly.

If the treatment of measurements is made practical, with consideration for the proper use of slide rules, seven place logarithm tables, graphical methods, etc., it need not take on a wholly dry-as-dust appearance. There are suitable texts covering this phase of the subject, some of which merit a more general consideration than they have yet received.

VI. SUMMARY

The committee has called attention to the greatly increased importance of physics in relation to medicine, to the realization of this by medical men, and to the desire on their part for increased cooperation of physicists in medical research, and for better preparation in physics for the study of medicine. They have made the following recommendations, presenting the reasons which have governed them as fully as possible without unduly extending the length of this report:

First: That successful participation of physicists in medical research can best be secured by the appointment of one or more physicists on the staff of medical institutions. The duties of such men should include cooperation in research, advice in the application of physical methods and instruments in medical practice, and systematic instruction in one or more courses open to students or any other members of the institution who may desire it.

Second: As regards education in physics preparatory to medicine, they feel that in view of the other great demands on the time of the student, the amount of physics required of the average student for entrance to the medical school should be limited to one good course of general physics in college, but they urgently recommend that this course fulfill the following conditions as essential to the accomplishment of its purpose:

a. The course should aim to instil the fundamental principles and concepts of the science as a whole, and the ability to apply them, rather than to teach particular phenomena or methods, supposed to be appropriate to present medical practice. The student must be left in a position to extend his knowledge by his own efforts in accordance with the future development of his interests and the progress of medicine.

b. The course should, if possible, come in the second college year and be preceded by a year of college mathematics. This amount of preparation in mathematics is not excessive in view of the importance of physics to the medical student and the fact that physical chemistry, which requires a considerable use of mathematics, is also usually required for the medical school.

c. If a year of college mathematics cannot possibly precede the course in college physics, a good working knowledge of elementary trigonometry and logarithms should still be considered as an important pre-requisite. It should, therefore, so far as practicable, be required for entrance, if the course in physics is to come in the freshman year.

d. The committee estimates that to accomplish its purpose a total of at least 500 hours of the student's time will be required for the course, including class work, laboratory work, home study, and reading, and the minimum time and credit to be assigned to it in the curriculum should be 12 semester hours.

Third: In addition to the required course in general physics, an elective course should be provided, suitable for students who desire more knowledge of physics than the general course affords, but who expect to apply their knowledge to medicine or biology, rather than to engineering or physics. The additional training afforded by this course might be recognized by the medical school by accepting it from a limited number of students in lieu of some other requirement, for example, in lieu of a second year of biology. It should normally be taken in the last year of the college course, and be looked upon as an advantage accruing from a four-year preparatory course and usually out of the question in one of two years only.

Fourth: There should be provision in the medical school for one or more courses in biophysics, or physics applied to medicine, as electives, usually to be taken in the last years of the medical school course, after the student knows enough medicine to realize the importance of the subject, and has some idea of the field to which he intends to apply his knowledge, so that the course can be adapted to it.

June 12, 1922.